ALBERT-LUDWIGS-
UNIVERSITÄT FREIBURG

Algorithms for Radio Networks

Localization

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IIF
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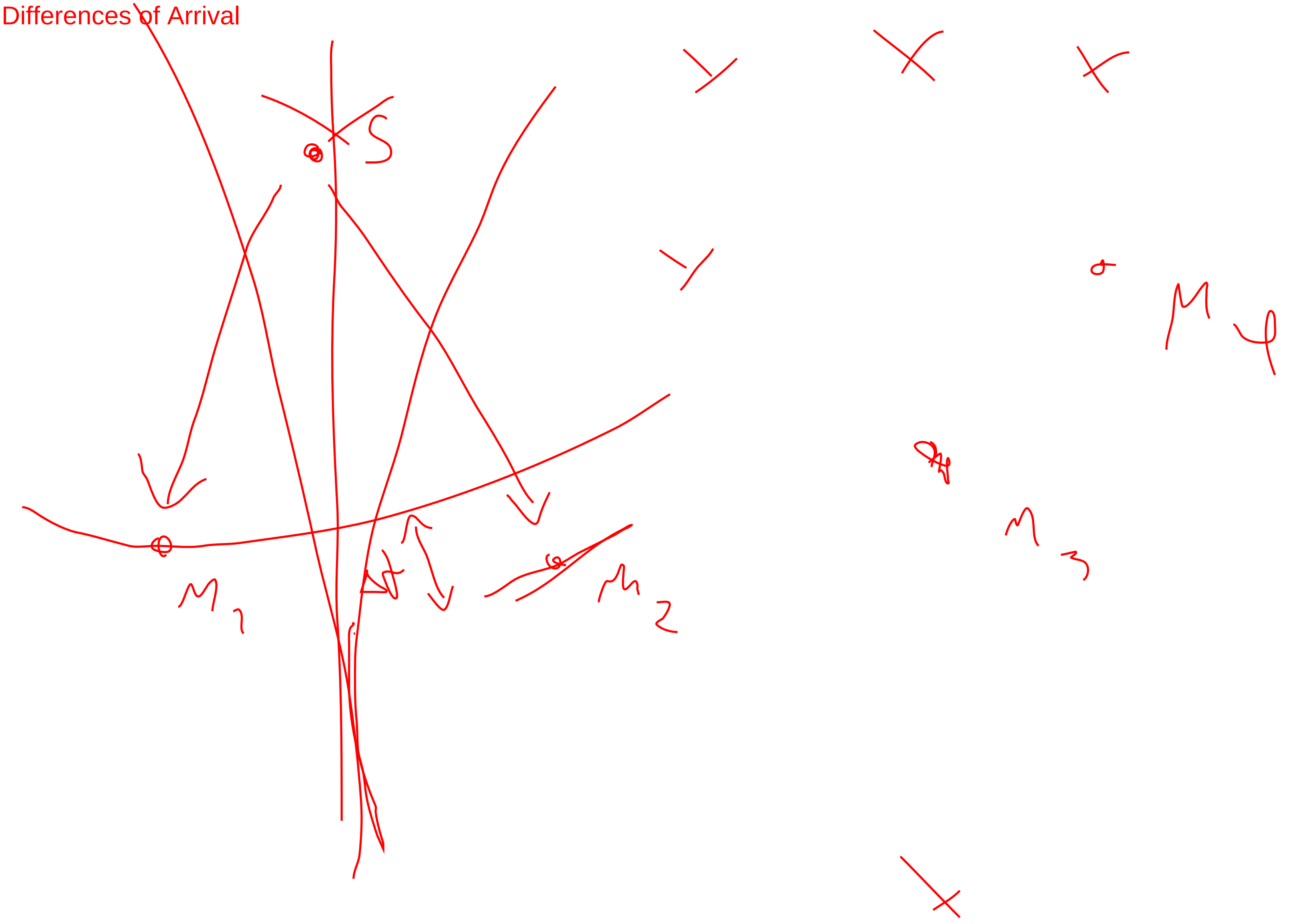
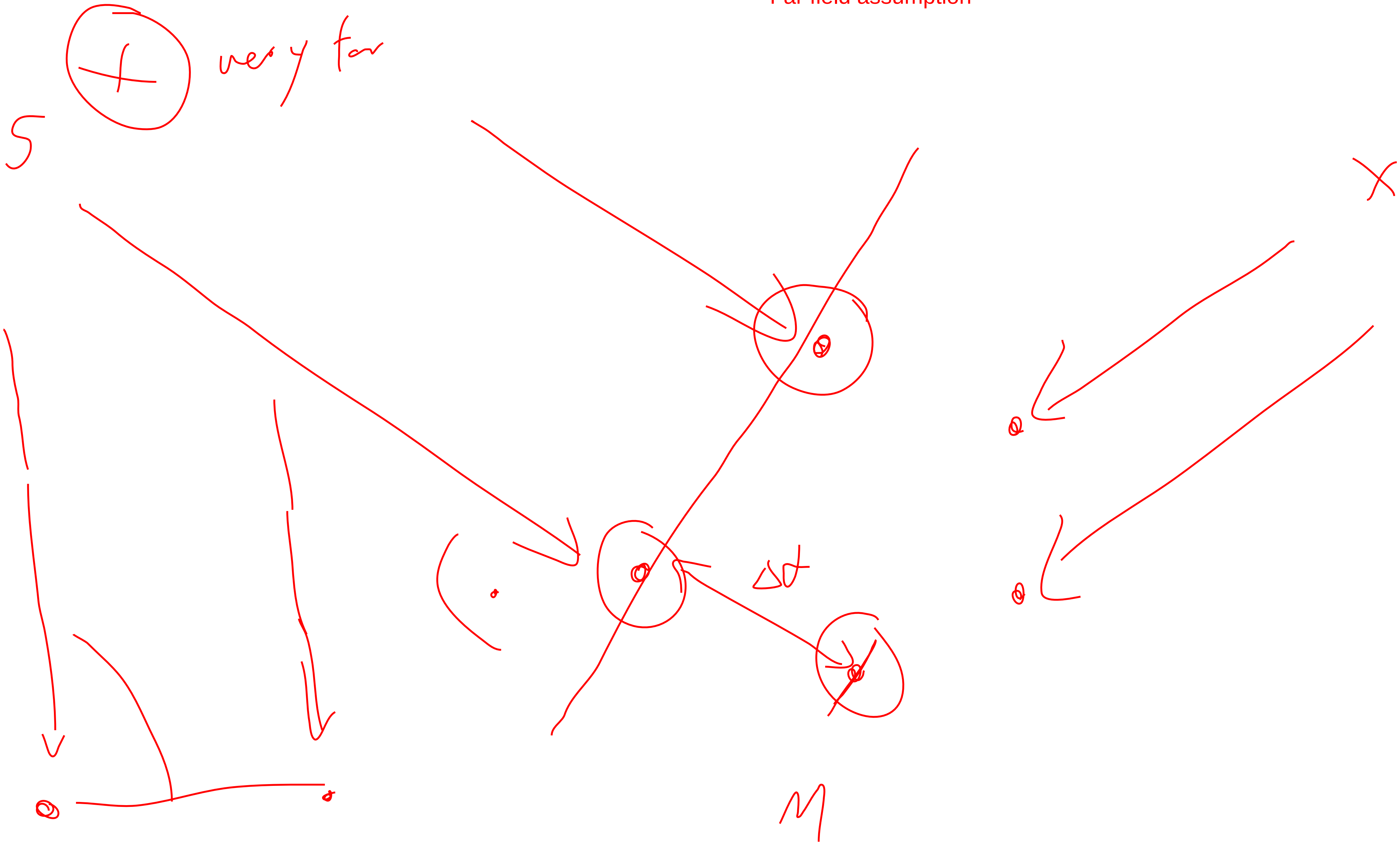
Time Differences of Arrival

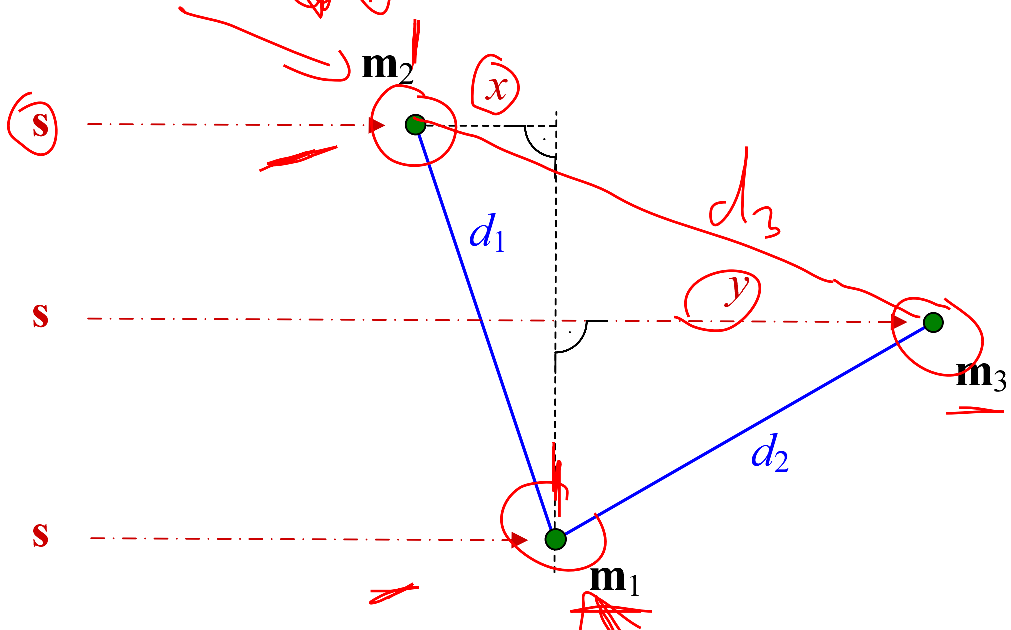


Far field assumption

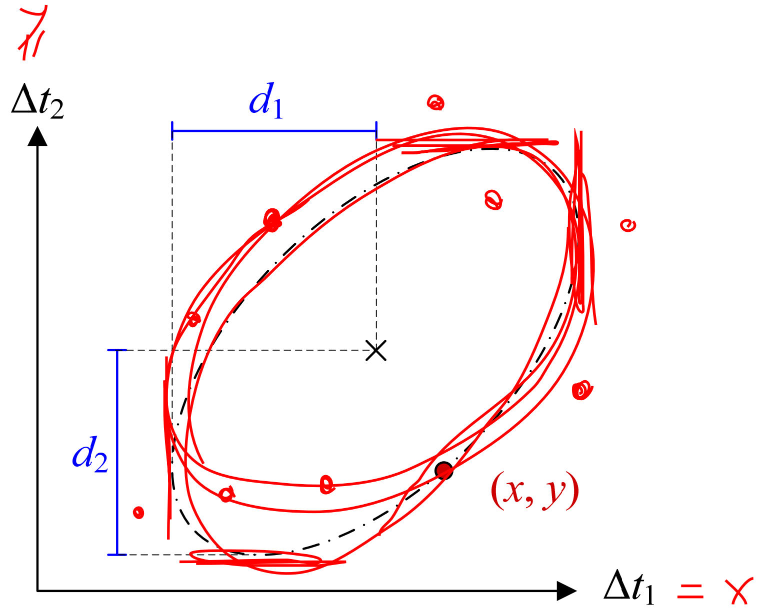


Anchor-free localization

- (3.) Assume that signals occur from far away:
  - "far-field assumption", linear frontier of signal propagation
- The Ellipsoid TDoA Method [Wendeberg, et al., TCS, 2012]
  - Time differences of *three* receivers form an ellipse

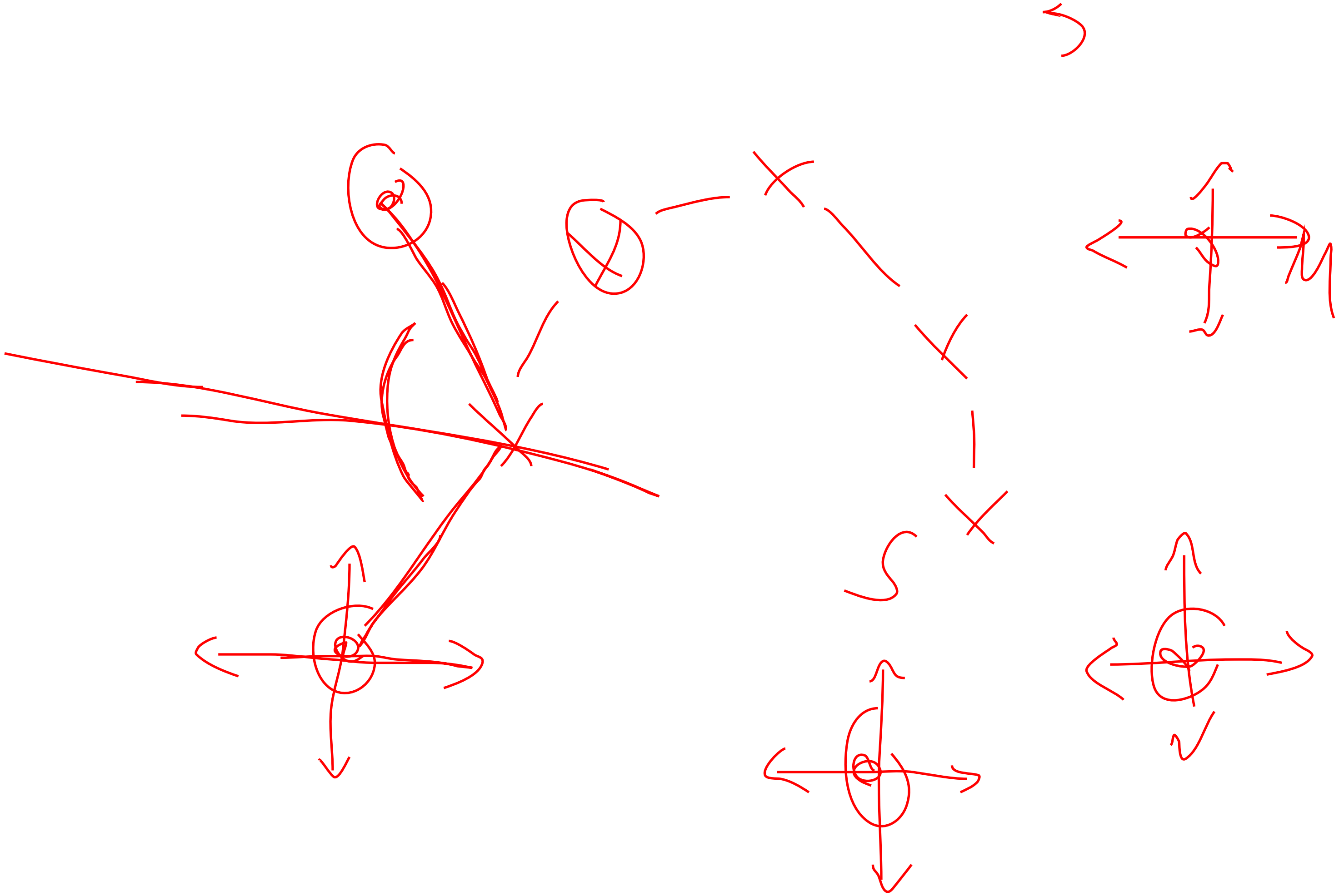


top-down view

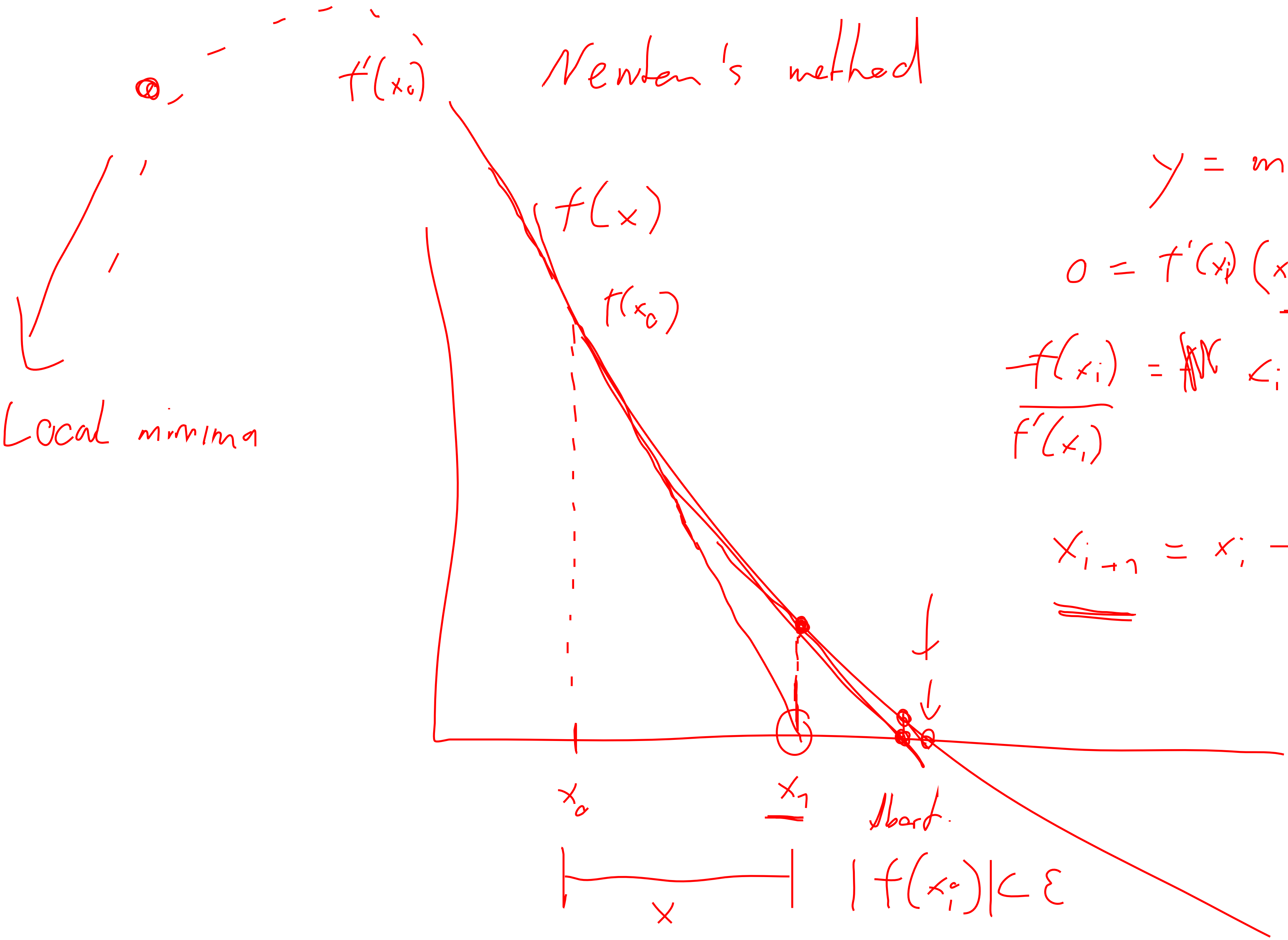


time differences

General setting Optimization



Newton's method



$$y = mx + c \quad | \quad y = 0$$

$$0 = f'(x_i)(x_{i+1} - x_i) + f(x_i)$$

$$-\frac{f(x_i)}{f'(x_i)} = x_{i+1} - x_i$$

$$\underline{\underline{x_{i+1} = x_i - \frac{f(x_i)}{f'(x_i)}}}$$

$$|f(x_i)| < \varepsilon$$

Multivariate

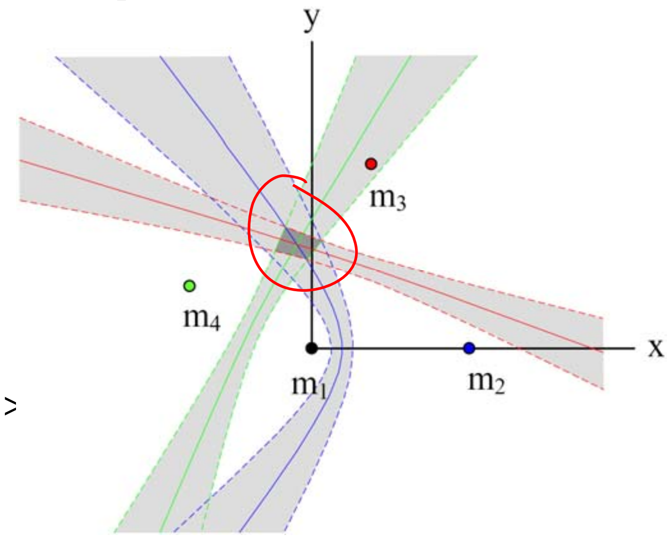
Gauss-Newton

→ Jacobian matrix

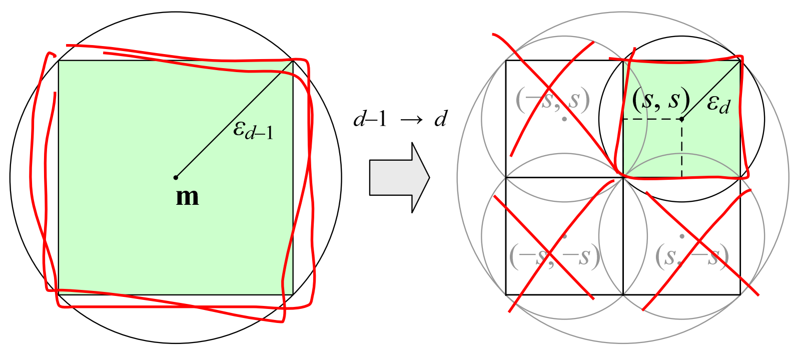
Anchor-free localization

- **(4.) Two-phased *branch-and-bound* algorithm in 2D**
  [Wendeberg and Schindelhauer, ALGOSENSORS 2012]

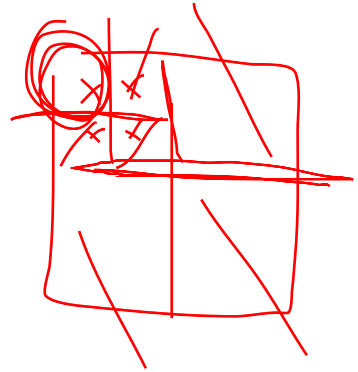
  1. **"Bound": Test sub-problems if feasible up to error $\varepsilon \sim s$ with regard to measure-ments Δt_{ij}. Satisfy**
     $$|\, \| m_i - s_j \| - \| m_1 - s_j \| - \Delta t_{ij} \,| \le \varepsilon \quad (i >$$
     or discard sub-problem



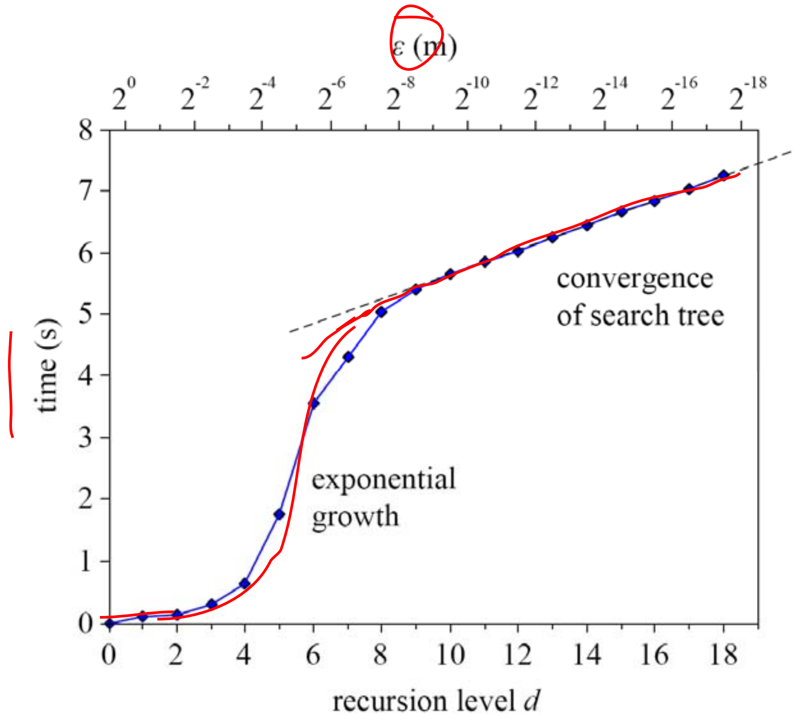
  2. **"Branch": Divide feasible problems of size s^n into sub-problems of size $(s/2)^n$**



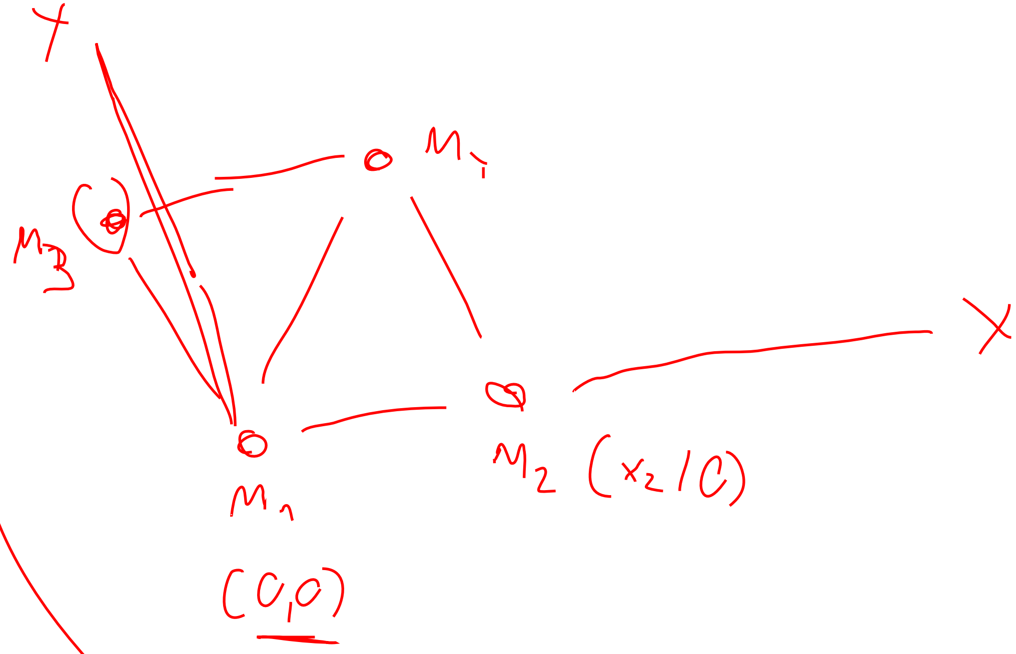
Anchor-free localization



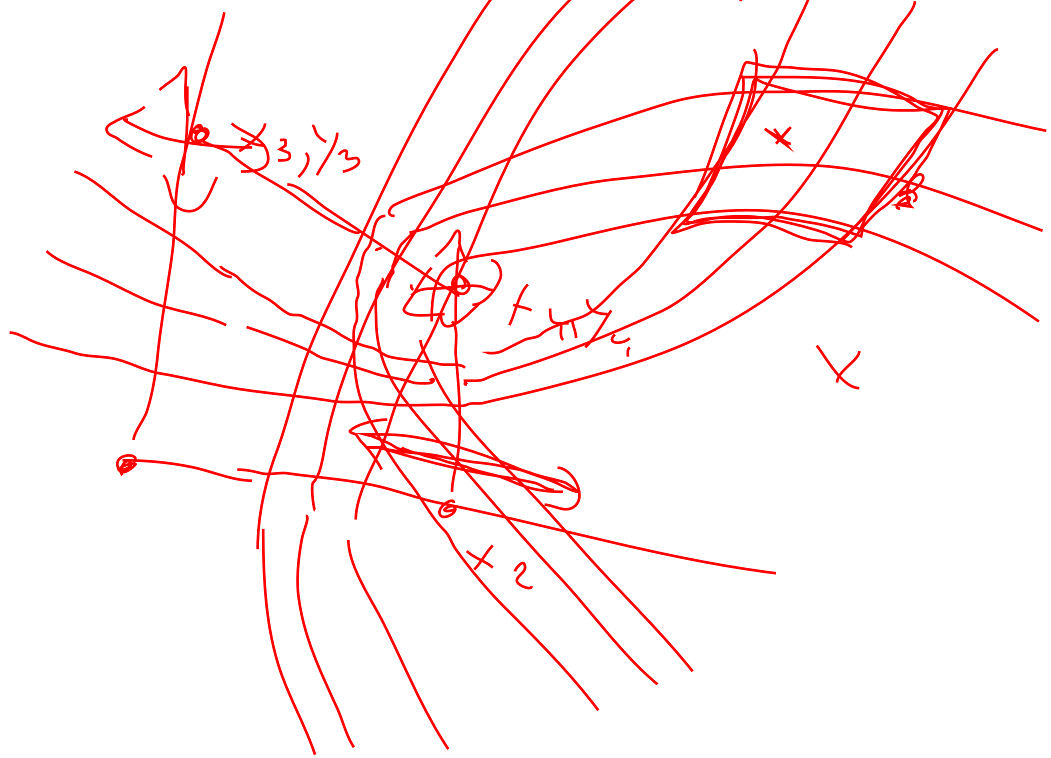
- **Numeric simulation**
  - **Solution always found up to bound ε**
  - **In case of measurement errors: Solution up to $\varepsilon_{\text{tdoa}}$**
- **Behavior of search tree**
  - **Breadth-first search**
  - **Exponential growth / convergence of search tree**
  - **Runtime:** $\mathcal{O}((\sqrt{2}/\epsilon)^{2n-3}mn^2)$



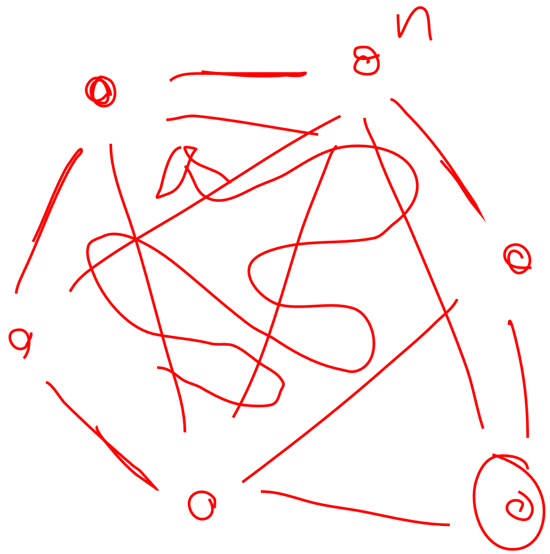
- **➔ Minimum case FPTAS to Calibration-free TDoA**



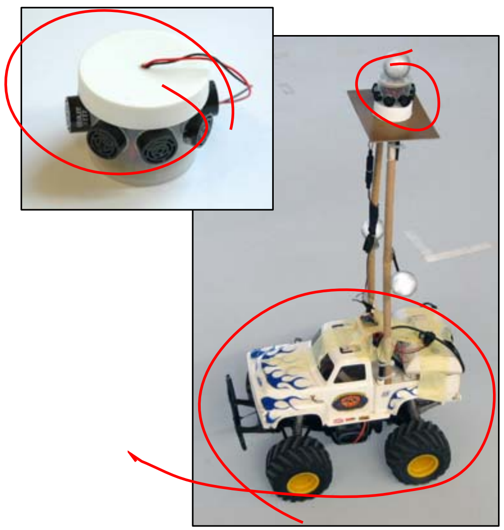
→ 5 variables



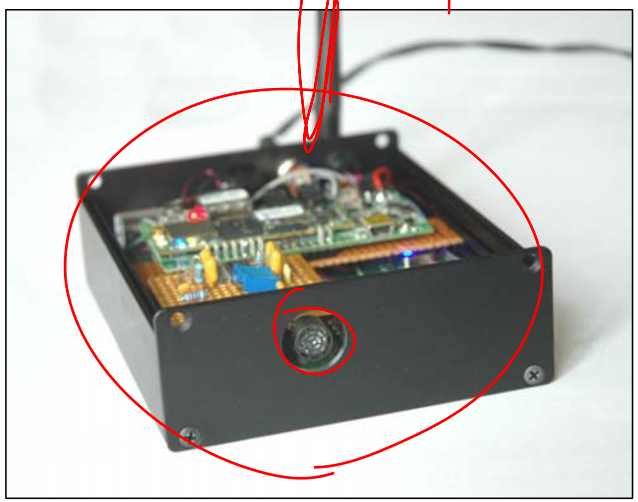
"Calibration-Free Tracking System"



- **Anchor-free TDoA Ultrasound Tracking System**
  [Wendeberg, Höflinger, Schindelhauer, and Reindl, LBS, 2013]
  - **In collaboration with IMTEK / Lab. for Electrical Instrumentation (EMP)**
  - **40 kHz ultrasound moving transmitter and fixed receivers**
  - **Receivers synchronized in a Wi-Fi network**

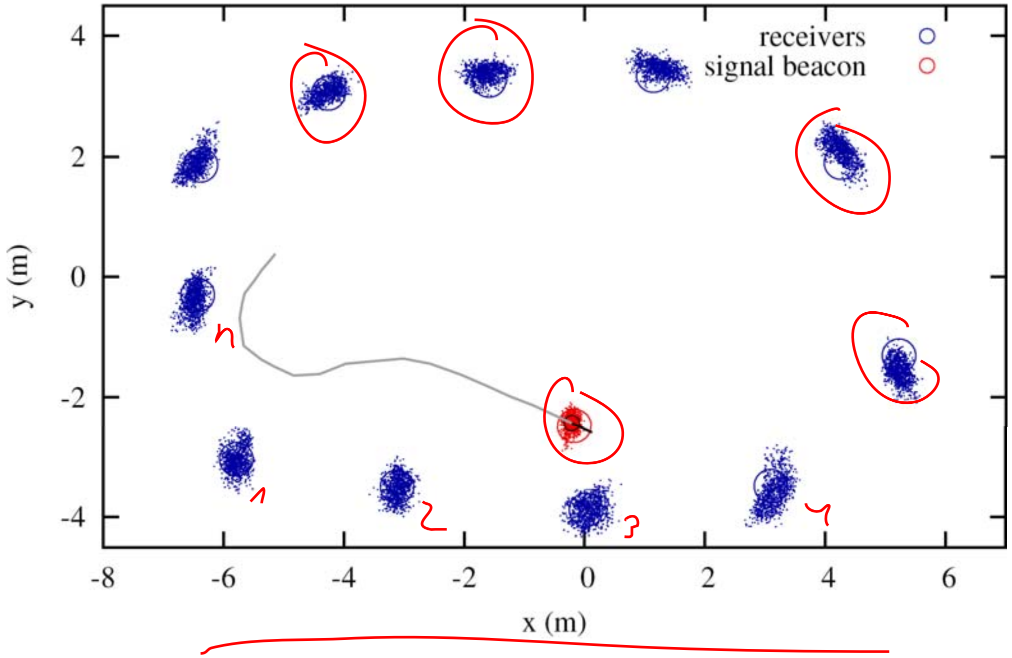


Wifi



"Calibration-Free Tracking System"

- Tracking system is "calibration-free"
  - Arbitrary placement of ultrasound receivers
  - Compute positions of receivers by TDoA measures
  - Precision of ~ 5 cm

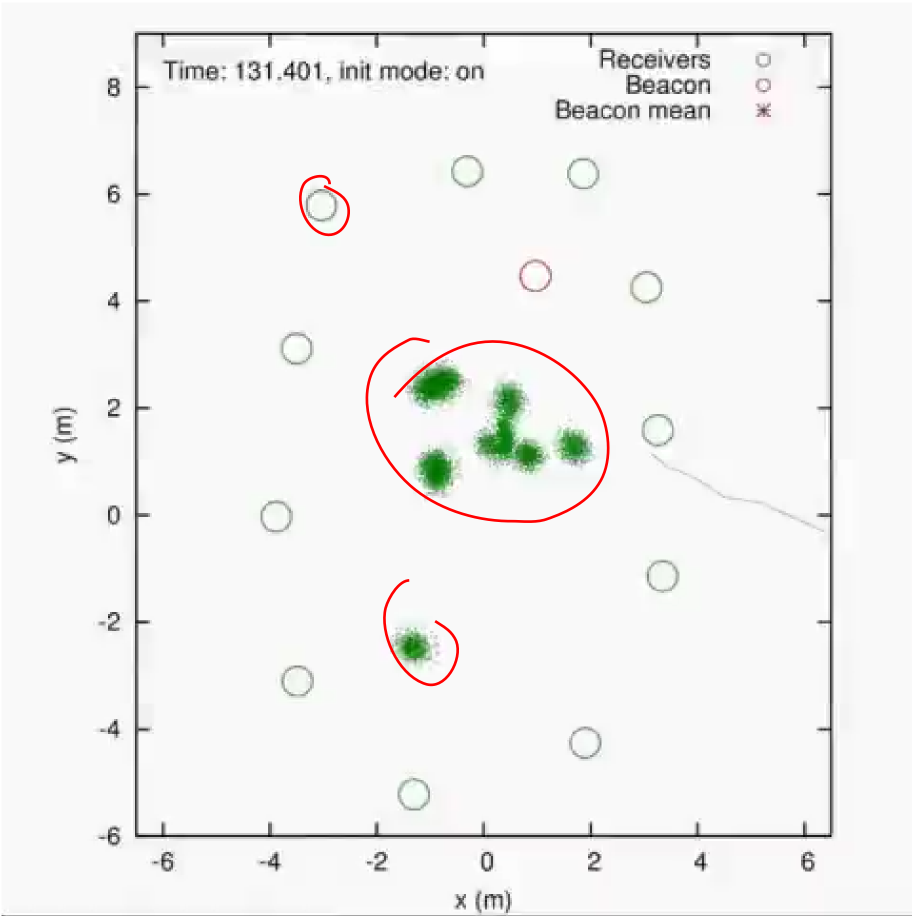


2D

1D

State $x = \begin{bmatrix} x_s \\ y_s \\ x_1 \\ y_1 \\ \vdots \\ x_n \\ y_n \end{bmatrix}$

“Calibration-Free Tracking System”



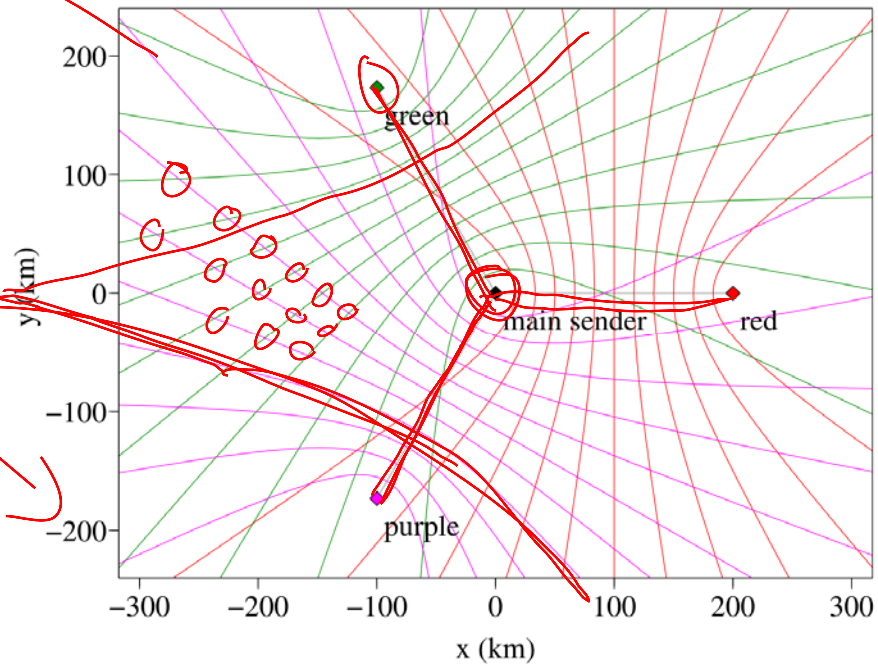
YouTube http://www.youtube.com/watch?v=V85wejcYyXs

Some More Available Localization Systems

- **Land stations**
  - **Decca**
  - **LORAN-C**
  - **Mobile cells**
  - **WLAN identification**
- **Satellite-based**
  - **NAVSTAR-GPS**
  - **GLONASS**
  - **Galileo**

Decca

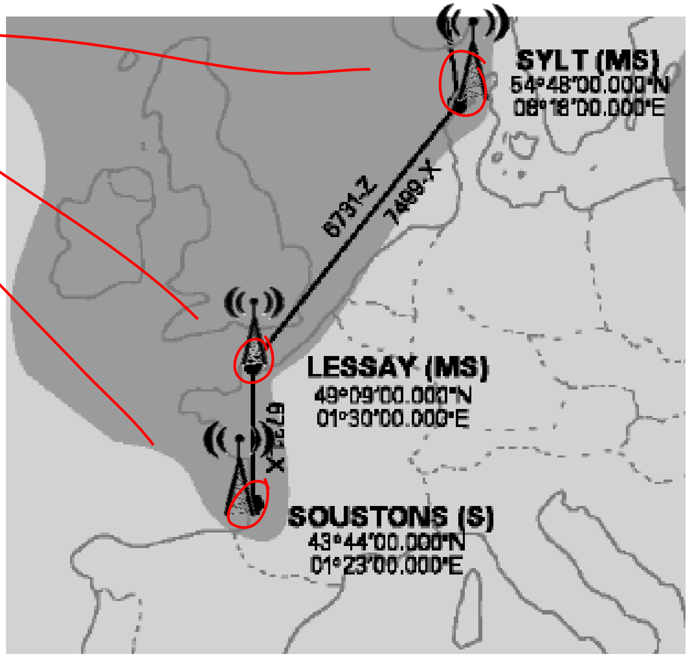
- W. O'Brien, Decca navigation system, ca. 1942 – 2000
- Hyperbolic multilateration
  - One main sender
  - Three slave senders (distance 100 – 200 km)
  - Senders synchronized
- TDoA by phase difference of continuous harmonics, e.g. $\{6f, 5f, 8f, 9f\}$, f = 14.167 kHz



- Point of departure must be known! (periodic phases)
- Range ca. 400 – 700 km, precision ca. 0.05 – 1 km

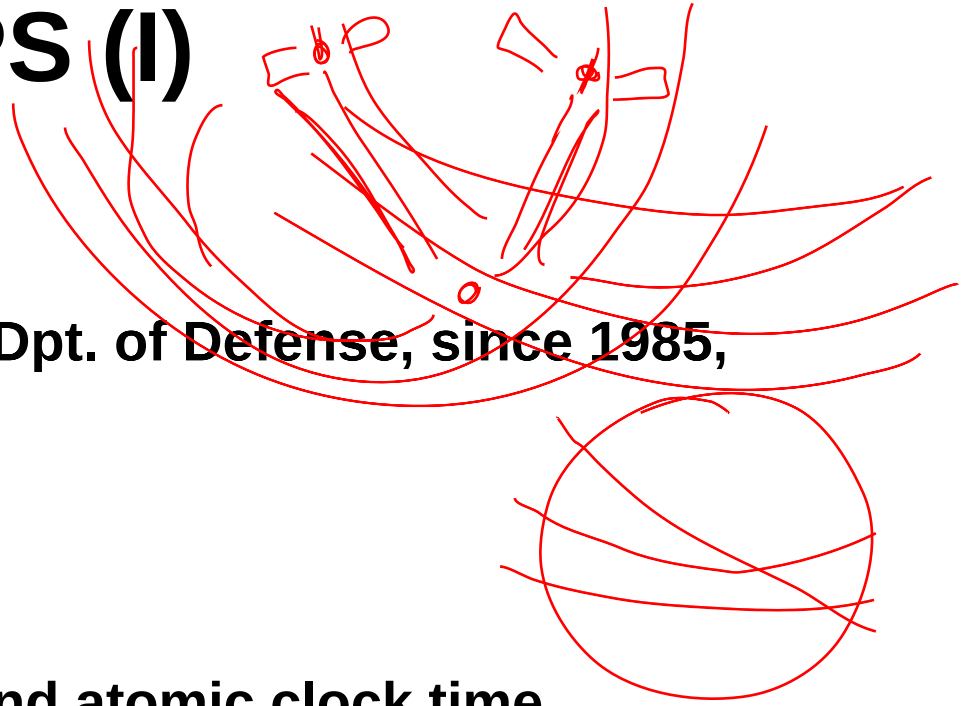
LORAN-C

- LOng RANge navigation system, 1957 – now
- Hyperbolic multilateration
  - Chains of senders (distance 100+ km)
- TDoA of discrete pulses of 100 kHz, identification of senders by CDMA (no overlap)
- Range up to 1,000 km, precision 0.01 – 0.1 km

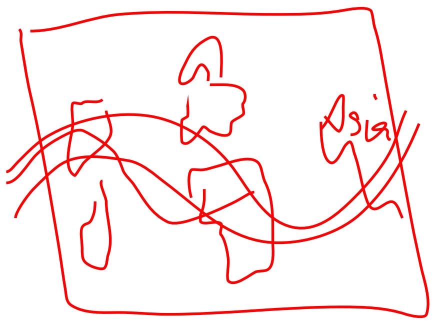


[Wikipedia]

GNSS: GPS (I)



- Global Positioning System (GPS), US Dpt. of Defense, since 1985, no “selective availability” since 2000
- 24+ GPS satellites
  - earth orbit 20,000 km
  - send ephemerides (trajectory data) and atomic clock time
  - Frequency: 1.228 / 1.575 GHz
- GPS receiver
  - measures TDoA of satellite messages (by correlation)
  - has no precise clock!
  - calculates “pseudoranges”, 3D coordinates and time
  - requires at least 4 satellites (more is better)



GNSS: GPS (II)

- GPS requires line-of-sight: No signal in forest, dense urban areas, indoors
- Precision: 5 – 15 m (good signal)
- Differential GPS
  - Reference receiver, compensating for atmospheric disturbances, precision up to 0.1 m
  - Modern geodetic systems: Even millimeters!

GNSS: GLONASS

- **GLONASS, russian GNSS, since 1993 (25 satellites)**
- **Technology similar to NAVSTAR-GPS**
- **Limited operation: in 2001 only 7 satellites alive, in 2011 available again (ca. 24 satellites)**
- **Loss of 3 satellites each in Dec. 2010 and in July 2013**
- **Supported by modern smart phones (Nokia Lumia series, Samsung Galaxy series, Apple iPhone 4S and later, and others)**

GNSS: Galileo

- **Galileo, european GNSS, adopted in 2008**
- **Technology similar to NAVSTAR-GPS**
- **Up to 30 satellites planned**
- **Availability expected for 2014 with 18 satellites**

Possible Improvements

- Combination of different methods
  - magnetic field
  - air pressure
  - sonar

Sensor fusion

- Kalman filter
  - Extension of Markov filters

≈ Particle filter

- Motion sensors
  - gyroscopes
  - acceleration sensors

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